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Detection Performance of Upgraded "Polished Panel" Optical Receiver Concept on the Deep-Space Network's 34 meter Research Antenna

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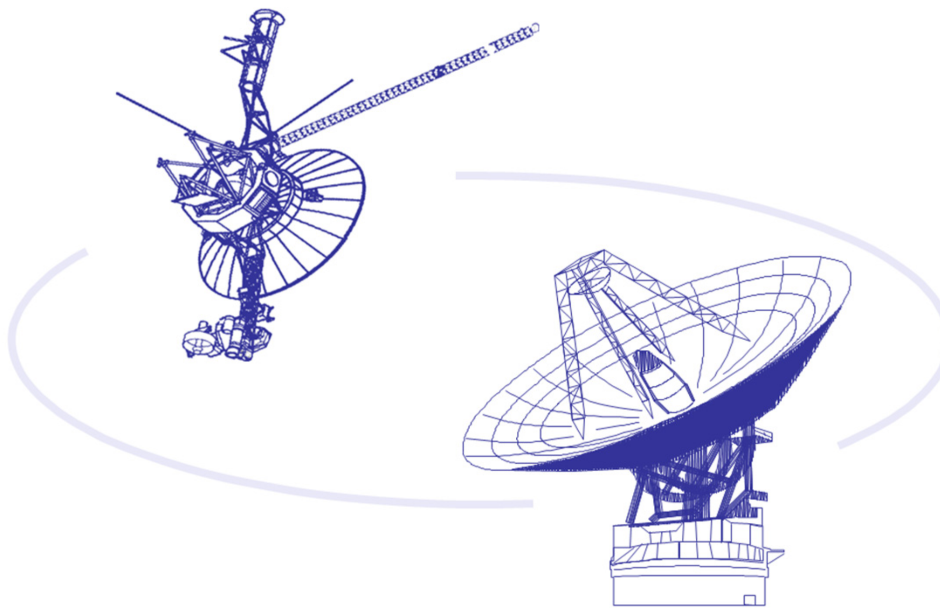
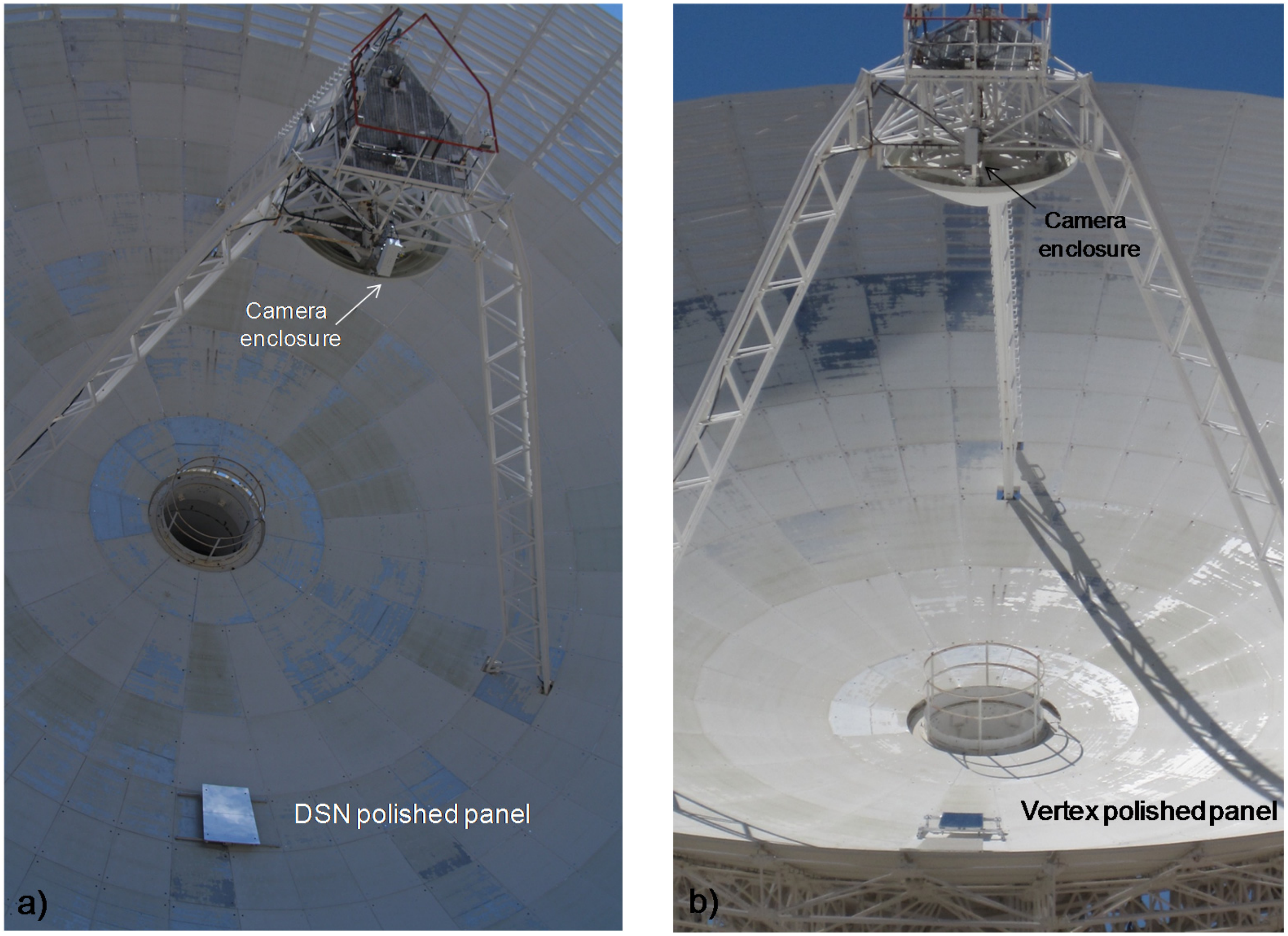


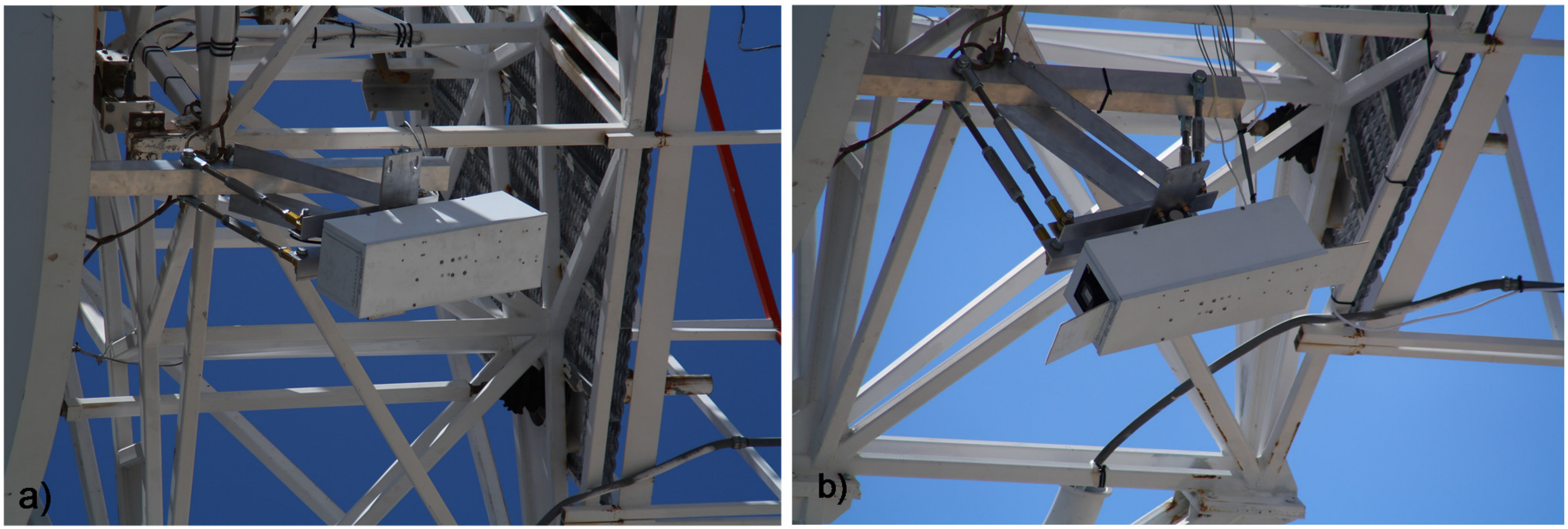


DSN and Vertex Polished Panels mounted on the 34 meter research antenna at DSS-13. a) DSN polished panel mounted on the main reflector, to help establish weather and dust resistance; b) Vertex polished panel mounted on the main reflector, closer to the center.

Vertex Polished Panel and Mounting Structure on DSS-13

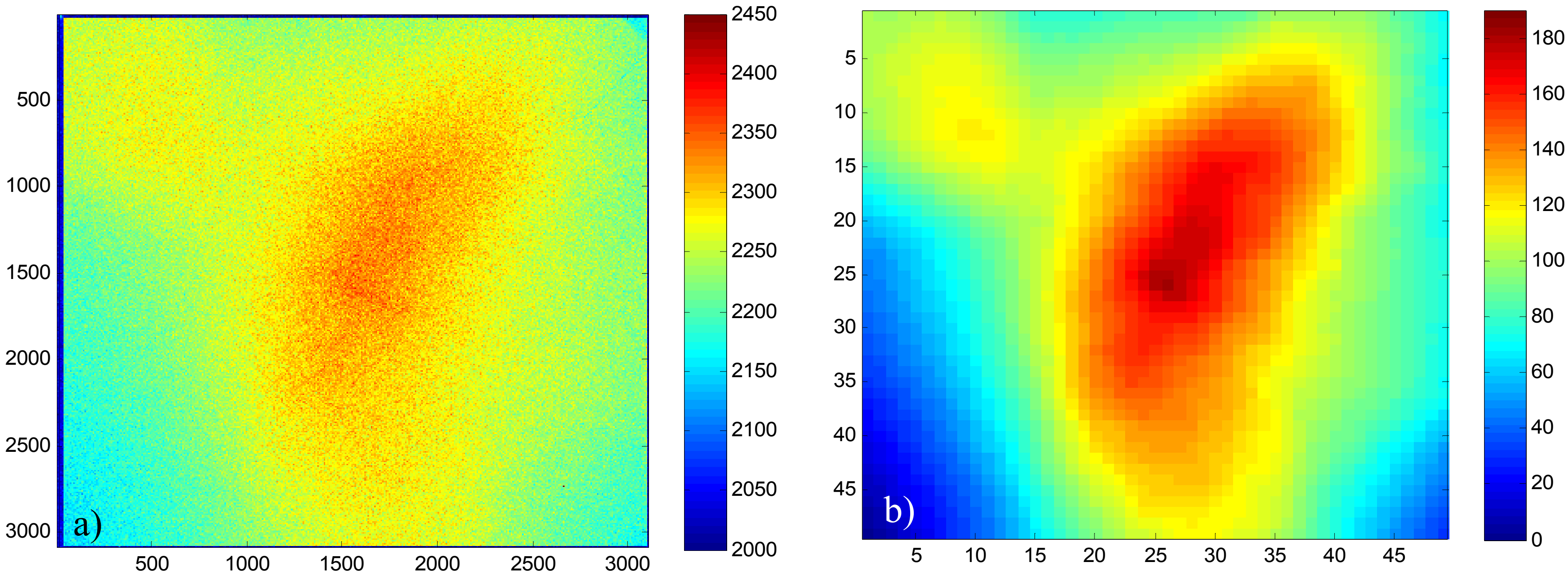
Polished aluminum panel manufactured by Vertex Antennentechnic, Germany, installed on the main reflector of the 34 meter antenna at DSS-13. Note parallel grooves due to milling process.

Remote controlled camera assembly mounted on the DSS-13 subreflector backup structure

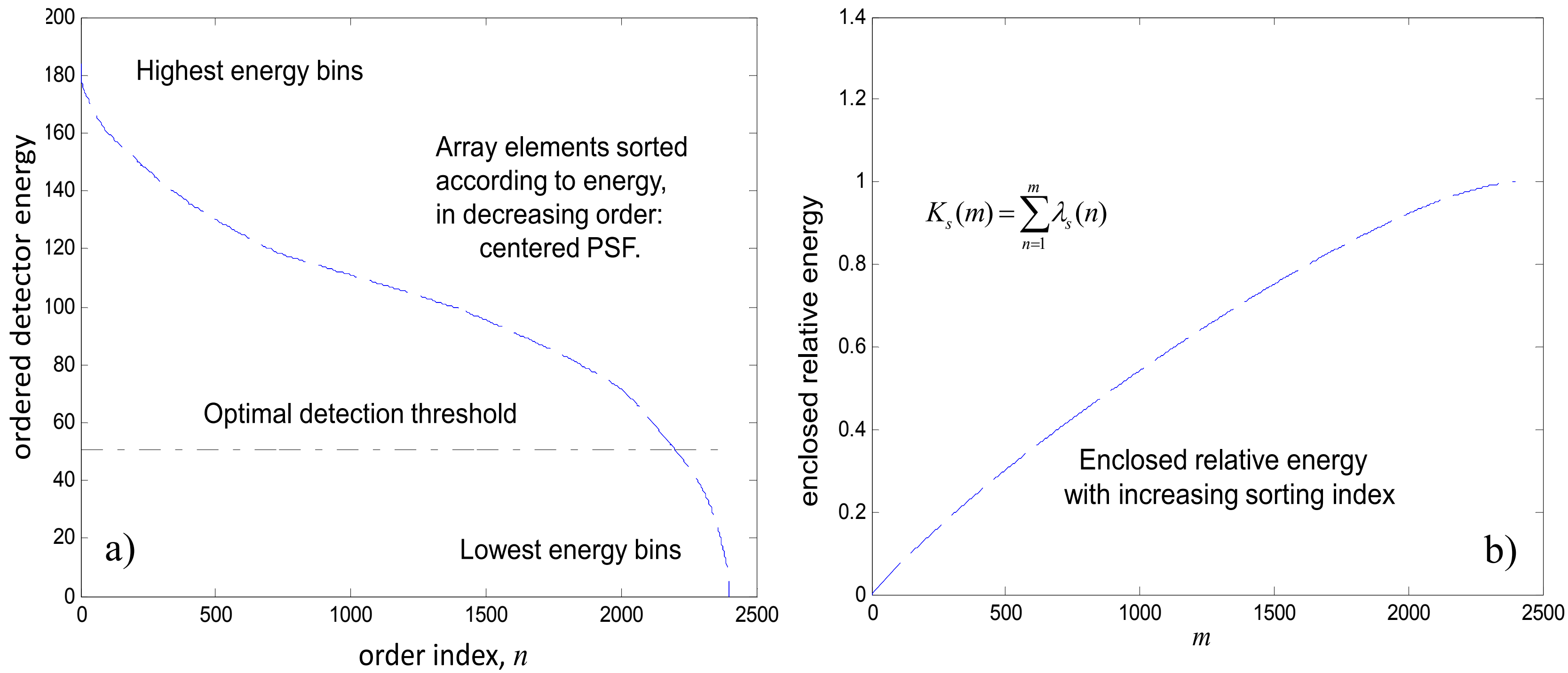


normally closed configuration **open configuration used for data-gathering**

Polished Panel PSF generated by Jupiter, recorded on September 8th, 2011

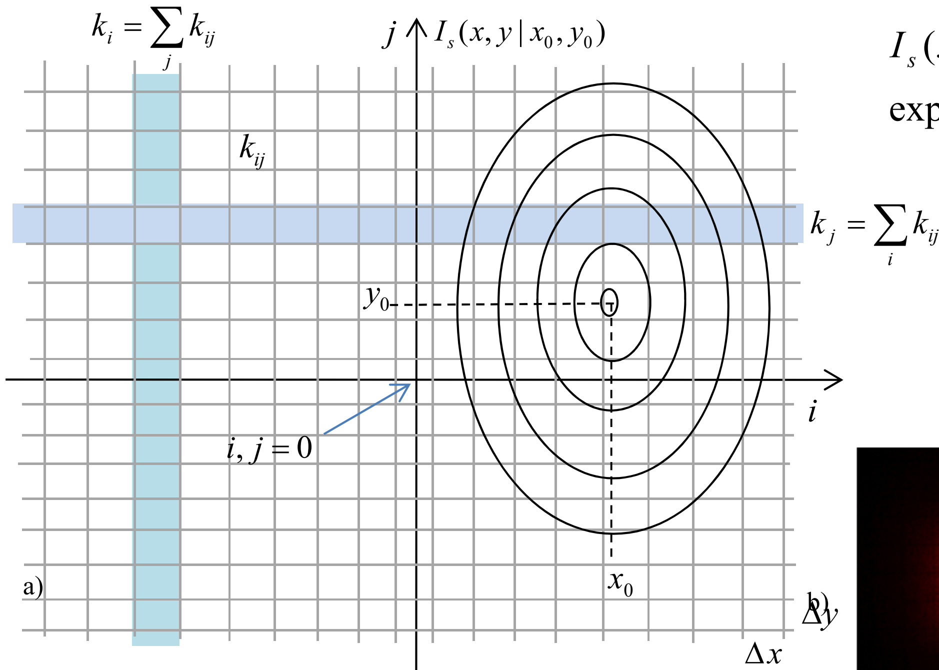


Centered PSF recorded by FLI camera: a) original 10 mega-pixel resolution showing "salt and pepper" pattern; b) smoothed 60X60 binned image showing the spatially averaged structure of the point-spread-function.



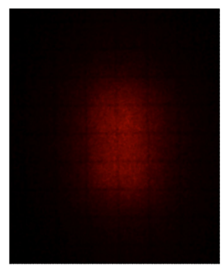
Communications processing of Jupiter PSF data: a) Detector elements sorted according to energy, for a centered PSF; b) accumulated relative energy in the first "m" sorted detector elements.

Mathematical model of Focal-Plane Intensity Distribution



Let $\Delta x = \Delta y = \Delta$, with no loss in generality

b)



$$I_s(x, y \mid x_0, y_0) = I_s\,(2\pi\,\sigma_s^2)^{-1} \times$$
$$\exp\{-[(x - x_0)^2 / 2\sigma_x^2 + (y - y_0)^2 / 2\sigma_y^2]\} \quad \text{watts/cm}^2$$

$$\lambda_s(i, j \mid x_0, y_0) = \int_0^T P_s(i, j \mid x_0, y_0)\, dt$$
$$\cong T\Delta^2 I_s(i\Delta, j\Delta \mid x_0, y_0)$$

$$p(k_{ij} \mid x_0, y_0) = [\lambda_s(i, j \mid x_0, y_0)]^{k_{ij}} \times$$
$$\exp[-\lambda_s(i, j \mid x_0, y_0)] / k_{ij}!$$

$$p(\mathbf{k} \mid x_0, y_0) = \prod_{i,j} [\lambda_s(i, j)]^{k_{ij}} \exp[-\lambda_s(i, j)] / k_{ij}!$$

a) Focal-plane model of pixel array, and elliptical PSF with pointing offsets , motivated by: b) experimentally determined point-spread function (PSF) for the high-quality Vertex panel, photographed on the JPL mesa test range.

Communications Receiver Performance, PPM Signals

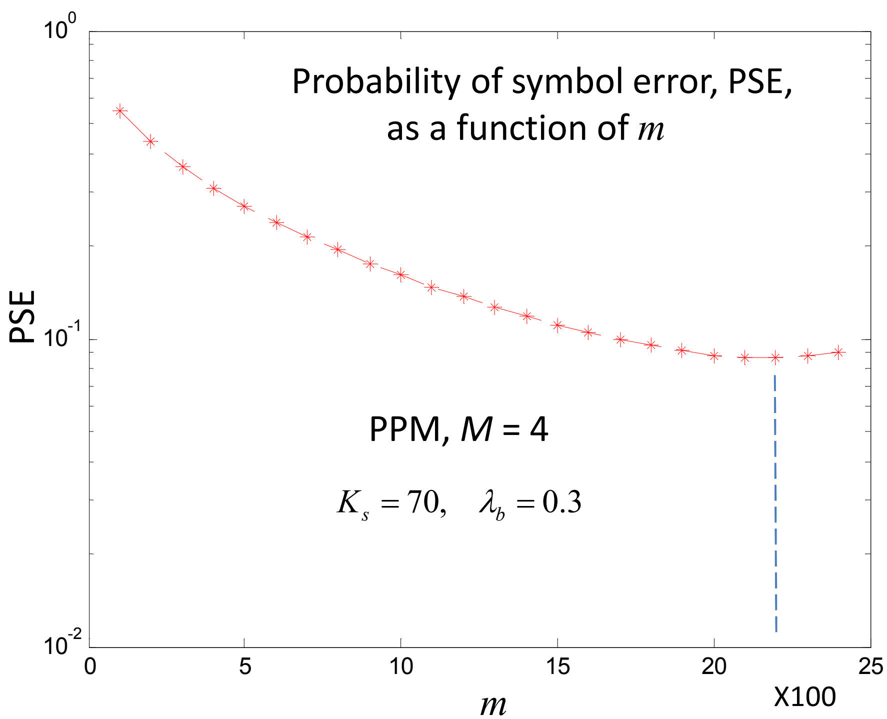
$$P_M^l(C) \ge \sum_{k=1}^{\infty} \frac{\left(K_s(m)+K_b(m)\right)^k}{k!} \exp\left[-\left(K_s(R)+K_b(R)\right)\right] \times \left\{ \sum_{j=0}^{k-1} \frac{\left(K_b(R)\right)^j}{k!} \exp\left[-\left(K_b(R)\right)\right] \right\}^{M-1}$$

$$P_M^u(E) \equiv 1 - P_M^l(C) \ge P_M(E) \cong P_M(E)$$

$$K_s(m) = \sum_{n=1}^{m} \lambda_s(n)$$

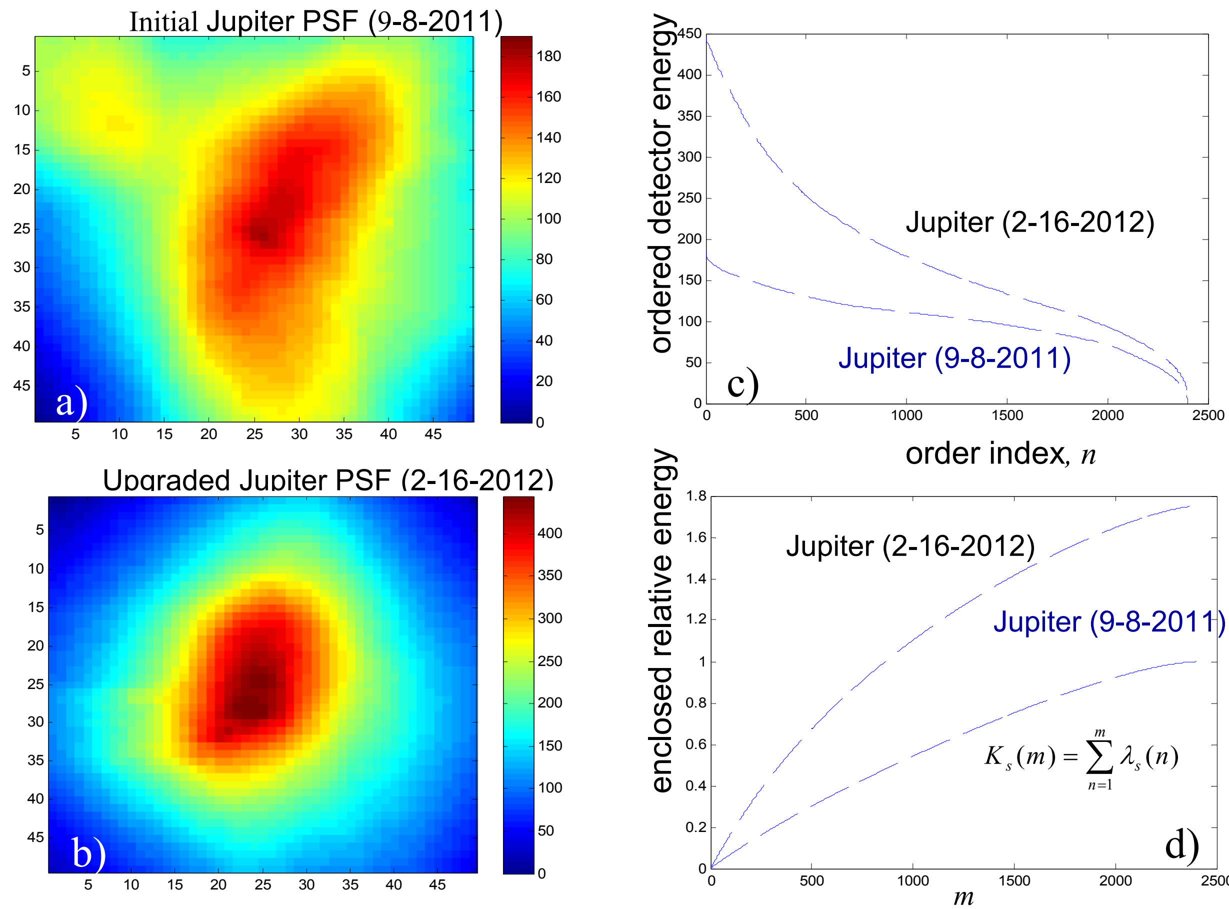
$$K_b(m) = m\lambda_b$$

$$P_M(C) \cong \int_{-\infty}^{\infty} dy\, Gsn[K_s(m)+K_b(m), y] \times \left[\int_{-\infty}^{y} dx\, Gsn[K_b(m), x] \right]^{M-1}$$



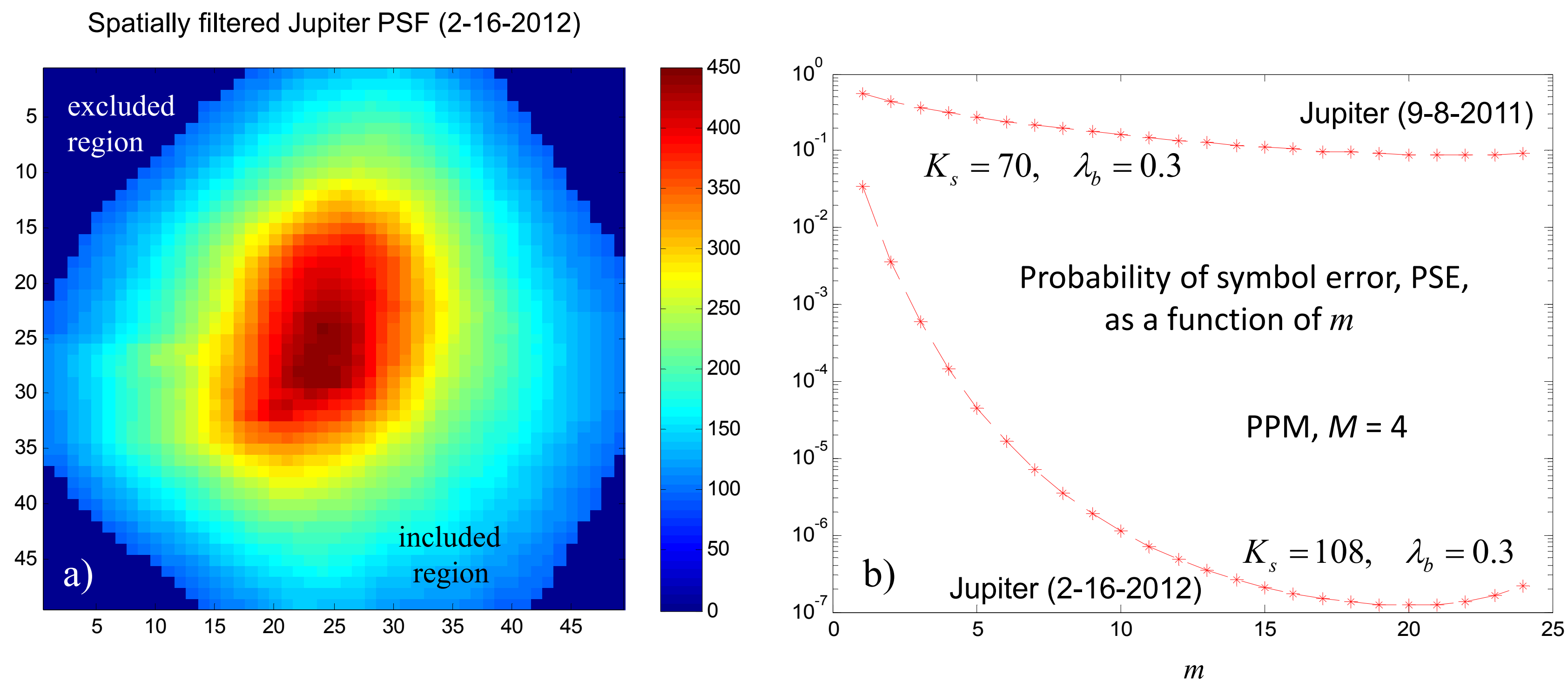
Detection performance of centered PSF: probability of symbol error for 4PPM signals as a function of *m*, for the case of 70 signal photons per symbol, and 0.3 background photons per slot per bin.

Point spread functions generated by the initial and upgraded panel mounting structures



a) Jupiter PSF obtained initially on 9/8/2011; b) improved Jupiter PSF after implementing upgrades to the panel mounting structure (2/16/2012); c) performance improvement quantified in terms of ordered detector energies; d) increased signal energy as a function of *m* due to better light concentration by the upgraded panel mounting structure.

Comparison of Vertex polished panel communications performance, before and after the mounting structure upgrade (removed tilt, minimized the panel's mechanical distortion



a) spatially filtered PSF showing the excluded regions at the four corners of the sensor; b) performance improvement illustrating the dramatic decrease in symbol error probability after the mounting structure upgrades have been implemented

SUMMARY AND CONCLUSIONS

- Initial optical communications experiments with a Vertex polished aluminum panel have been described
- The polished panel was mounted on the main reflector of the DSN's research antenna at DSS-13
- The PSF was recorded via remotely controlled digital camera mounted on the subreflector structure
- Initial PSF generated by Jupiter showed significant tilt error and some mechanical deformation
- After upgrades, the PSF improved significantly, leading to much better concentration of light
- Communications performance of the initial and upgraded panel structure were compared
    - After the upgrades, simulated PPM symbol error probability decreased by six orders of magnitude

- Work is continuing to demonstrate closed-loop tracking of sources from zenith to horizon, and better characterize communications performance in realistic daytime background environments